

Hadrons in AdS/QCD correspondence.

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We present an holographical soft wall model which is able to reproduce not only Regge spectra for hadrons with arbitrary integer spin, but also with spin $1/2$ and $3/2$, and with an arbitrary number of constituents. The model includes the anomalous dimension of operators than create hadrons, together with a dilaton, whose form is suggested by Einstein equations and the AdS metric used.

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I. INTRODUCTION.

From its beginnings, progress in QCD at low energies has seen impeded because there are no good tools available in order to work with strongly coupled Yang Mills theories. Nevertheless, in the last few years the AdS / CFT correspondence, or more generally the use of Gauge / String dualities, has provided a new approach that could improve this situation.

At present a dual to QCD is unknown, but a simple approach known as Bottom - Up has been quite successful. In fact, this kind of models gives us a way to deal with QCD that includes counting rules at small distances and confinement at large distances, and has been shown to be successful in several concrete QCD applications, such as in hadronic scattering processes [1, 2, 3, 4], hadronic spectra [5, 6, 7, 9], hadronic couplings and chiral symmetry breaking [10, 11, 12], quark potentials [13, 14, 15] and weak hadronic decays [16].

As was shown by Polchinski and Strassler [1], it is possible to simulate confinement introducing a cut off in the holographic coordinate z . This kind of models is known as hard wall models (HW), albeit phenomenologically they have problems, since the obtained spectra does not have Regge behavior. To remedy this it is necessary to introduce a soft cut off, using a dilaton field [6, 10], or using a warp factor in the metric [17, 18]. These models are called soft wall models (SW).

In the literature it is possible to find holographic models applied to glueball and mesons, which exhibit a linear dependence between the hadronic mass squared and both the angular momenta and the radial quantum number. However, this situation is different in the baryonic sector, where Regge like spectra could be obtained considering models without dilaton and using a warp factor in the AdS metric [7], or using integrability method for AdS / CFT equations [8]. Apart from this, with the exception of glueballs, exotic hadrons have not been considered in a general way, except in Ref. [9], where general scalar hadrons were discussed.

This work aims on one side to extend the ideas presented in [9], in order to consider not only hadrons with arbitrary integer spin, but also with spin $1/2$ and $3/2$, and with an arbitrary number of constituents, in a SW model that exhibits Regge behavior for these hadrons.

Moreover, we include the anomalous dimension of operators which create the hadrons that we consider. For these purposes a crucial point is to consider a different dilaton than the usual quadratic choice.

In the usual SW models, the dilaton is factorized from the AdS Dirac equation, and therefore there is no advantage or improvement over the HW situation in this case. As we will see soon, the inclusion of the anomalous dimension allows us to improve this aspect.

To take into account anomalous dimensions is not only motivated by the previous argument, since in the AdS / CFT context each operator in the CFT side is related to an AdS mode in the bulk, according to a specific dictionary. Nevertheless, in order to apply the correspondence to a theory like QCD, it is important to consider that with the exception of conserved currents, the operators have dimensions that are scale dependent due to anomalous dimensions, and this aspect should be included in models applied to QCD based in the correspondence. This point was developed in [24], where the anomalous dimension introduced a z dependence in the mass of AdS modes associated to operators, and in this way it could affect other quantities that depend on this scale.

Another aspect that needs to be stressed is that these holographic models consider QCD in the conformal limit, where it is weakly coupled due to asymptotic freedom. As a result, it is far from obvious that the use of a classical, weakly curved 5D background is justified, because you can expect a dual of QCD like a string theory on some highly curved space (as noted for instance in [6]). However, despite this possible problem, it is interesting to try to investigate if a classical 5D background might serve as phenomenological useful approximation to a holographical dual of QCD, and many Bottom - Up models show a remarkable agreement with experimental data and this work must be considered in this perspective.

The present work has been structured as follow. Section II is dedicated to hadrons with an integer arbitrary spin. In section II we consider hadrons with spin $1/2$, and in IV we show our results, which include hadronic spectra and the pion form factor. Finally we present in section V some conclusions.

II. HADRONS WITH ARBITRARY INTEGER SPIN.

We begin by considering an asymptotically AdS space defined by the metric

$$ds^2 = e^{2A(z)}(\eta_{\mu\nu}dx^\mu dx^\nu), \quad (1)$$

and the action for arbitrary integer spin modes is [6, 19]

$$I = \frac{1}{2} \int d^5x \sqrt{g} e^{-\Phi(z)} [\triangle_N \phi_{M_1 \dots M_S} \triangle^N \phi^{M_1 \dots M_S} + m_5^2 \phi_{M_1 \dots M_S} \phi^{M_1 \dots M_S}], \quad (2)$$

where $\Phi(z)$ is a dilaton field that only depends on the holographical coordinate z .

From this action, the equation of motion for the part propagating in the bulk can be written in general as [19]

$$\partial^2 \varphi - (\partial B(z)) \partial \varphi + [M^2 - m_5^2 e^{2A(z)}] \varphi = 0, \quad (3)$$

Here the following equation was used

$$B(z) = \Phi(z) - k(2S - 1)A(z), \quad (4)$$

where k is a constant and S corresponds to the spin of the mode considered.

As was mentioned before, we introduce some modifications with respect to the traditional SW models, where in general an AdS metric ($A(z) \sim -\ln(z)$) and a quadratic dilaton are considered. In this work the dilaton that we use is suggested by Einstein's equations [20, 21, 22], which together with other modifications to be made explicit a bit later, will allow us to obtain a Regge type spectra.

Let us see how the specific form for the dilaton can be obtained. We start with the action for 5D gravity coupled to a dilaton [20, 21, 22]:

$$S = \frac{1}{2k^2} \int d^5x \sqrt{g} \left(-R - V(\Phi) + \frac{1}{2} g^{\mu\nu} \partial_\mu \Phi \partial_\nu \Phi \right), \quad (5)$$

where k is Newton's constant in 5D and $V(\Phi)$ is the scalar field potential. From equation (1), we find the coupled Einstein's equations

$$6A'^2 - \frac{1}{2} \Phi'^2 + e^{2A(z)} V(\Phi) = 0, \quad (6)$$

$$3A'^2 + 3A'' + \frac{1}{2} \Phi'^2 + e^{2A(z)} V(\Phi) = 0, \quad (7)$$

$$\Phi'^2 + 3A' \Phi - e^{2A(z)} \frac{dV}{d\Phi} = 0. \quad (8)$$

Einstein's equations, (6) and (7), determine the dilaton directly from the metric as:

$$\Phi' = \sqrt{3A'^2 - 3A''}. \quad (9)$$

Our model is defined by

$$A(z) = \rho \ln \left(\frac{R}{z} \right), \quad (10)$$

where ρ is a constant. With this choice

$$\Phi(z) = \lambda \ln(z), \quad (11)$$

where $\lambda = \sqrt{3\rho(\rho - 1)}$ and in order to get equations with exact solutions, we will use $\lambda = 2$.

With this, and considering $\beta = -k(2S - 1)$, equation (3) changes to

$$\partial^2 \varphi - \left(\frac{\lambda}{z} - \frac{\beta}{z} \right) \partial \varphi + \left[M^2 - \frac{m_5^2 R^2}{z^2} \right] \varphi = 0. \quad (12)$$

The hadronic spectra is obtained from this equation, but as was shown for the scalar case in [9], the form of $m_5^2 R^2$ must be obtained considering the AdS / CFT dictionary, according to which, modes of the gravity theory and physical states of the gauge theory satisfy an UV boundary condition at $z \rightarrow 0$. More specifically, for a dual state $|i\rangle$ with spin 0 one must select solutions with behavior $\varphi(z) \rightarrow z^\Delta$ when $z \rightarrow 0$, where Δ is the conformal dimension of the gravity mode, and which must be equal to $[O]$, the dimension of the operator that creates the state $|i\rangle$ in the gauge theory. Modes with spin S need an additional factor z^{-S} , and then the boundary condition is generalized when $z \rightarrow 0$ and the dimension of the operator $[O]$ is changed to the respective twist τ [1, 23]

$$\varphi(z) \rightarrow z^\tau \quad \text{and} \quad \tau = [O] - S.$$

Different values for the product $m_5^2 R^2$ are related to different kinds of hadrons, and for this reason it is necessary to analyze the possible values for this product. This is achieved by equating the conformal dimension (Δ) of the mode propagating in AdS with the dimension of the operator that creates hadrons ($[O]$). At this point we introduce additional modifications with respect to traditional holographic models.

In the first place we consider the conformal dimension of the AdS modes, which is extracted from the behavior of the solutions of (12) when $z \rightarrow 0$. Thus

$$\Delta = \frac{1}{2}(1 - \beta + \lambda) + \frac{1}{2} \sqrt{\beta^2 + 4m_5^2 R^2 - 2\beta(1 + \lambda) + (1 + \lambda)^2}. \quad (13)$$

We also need the dimension of the operator that creates hadrons, where we have included a term that represents the anomalous dimension of this kind of operators. In principle this dimension can be written as

$$[O] = \Delta_0 + L + \delta, \quad (14)$$

where Δ_0 has contributions from quarks, antiquarks and/or gluons, L is a contribution coming from the angular momentum and δ is the anomalous dimension.

The anomalous dimension is proportional to the coupling constant [24], which in turn is related in holographical models to the dilaton, in the form $\sim e^{\Phi(z)}$ [20, 21]. According to the correspondence, the holographical coordinate is related to the energy of the theory that lives in the edge, and then the anomalous dimension that we are considering is a quantity that depends on energy. With this in mind, the τ for the operator can be finally written as

$$\tau = \Delta_0 + L + \omega e^{\Phi(z)} - S, \quad (15)$$

where ω is a constant.

Now we have expressions for both Δ and τ . Equating them gives a result for $m_5^2 R^2$, which is

$$m_5^2 R^2 = (\Delta_0 + L - S + \omega z^2)(\Delta_0 + L - S - 3 + \beta + \omega z^2), \quad (16)$$

where we took $\lambda = 2$. This choice allows us to get analytical solutions with Regge behavior from equation (12).

Using this in (12), the normalizable solutions are

$$\varphi(z) = C e^{-\frac{1}{2}\omega z^2} z^{\Delta_0 + L - S} L_n^m(\omega z^2), \quad (17)$$

where $L_n^m(x)$ are Laguerre polynomials, and

$$m = -1 + \frac{1}{2}(-1 + \beta + 2L - 2S + 2\Delta_0),$$

$$n = \frac{M^2 + 2\omega}{4\omega} - \left[-1 + \frac{1}{2}(-1 + \beta + 2L - 2S + 2\Delta_0)\right] - 1$$

$$n = 0, 1, 2, \dots$$

From the last equation we get the spectrum, which is

$$M^2 = 4\omega \left[n + L + \left(\Delta_0 + \frac{\beta}{2} - 1 - S \right) \right]. \quad (18)$$

In (17) C is a normalization constant, which can be fixed using

$$\int_0^\infty dz z^\beta e^{-\Phi(z)} |\varphi(z)|^2 = 1. \quad (19)$$

III. SPIN 1/2 HADRONS.

As was said before, the dilaton field can be factorized from the Dirac AdS equation, and for this reason this field does not have any influence over the spectrum in a traditional SW model. Nevertheless, since in our model we consider anomalous dimensions, m_5 has a dependence on the dilaton, and in this way this field can affect the spectrum. This allows us to get the desired Regge behavior in this sector, as we will see soon.

According to [25] the Dirac equation with dilaton in AdS space can be written as

$$\left(\not{D} - \frac{1}{2} e_A^M \gamma^A \partial_M \Phi - m \right) \Psi(x^\mu, z) = 0,$$

where $\not{D} = e_A^M \gamma^A D_M$ and e_A^M correspond to a $(d+1)$ -bein.

Dual modes to baryons can be decomposed into left and a right pieces [7]

$$\Psi(x^\mu, z) = \left[\frac{1 + \gamma^5}{2} f_+(z) + \frac{1 - \gamma^5}{2} f_-(z) \right] \Psi_4(x^\mu),$$

where $\Psi_4(x^\mu)$ satisfies the Dirac equation in four dimensions.

Following the procedure described in [25], the dilaton field can be factorized, and applying \not{D} over the Dirac equation and using $\gamma^5 f_\pm = \pm f_\pm$, we get an equation for the part that is propagating in the bulk, which is

$$\partial^2 f_\pm - \frac{4}{z} \partial f_\pm + \left[M^2 + \frac{6}{z^2} - \frac{m_5^2 R^2}{z^2} + \frac{\gamma m_5 R}{z^2} \right] f_\pm = 0, \quad (20)$$

where $\gamma = \pm 1$, depending on whether we are considering the left or right part.

This equation is the same that one gets in HW models, with solutions that are Bessel functions and whose spectrum in this case does not have Regge behavior [5]. The last point is true when $m_5 R$ is independent on z .

Considering the solutions for (20) it is possible to see that the conformal dimension is

$$\Delta = \begin{cases} \frac{5}{2} + \frac{1}{2}|1 - m_5 R| & \text{if } \gamma = 1 \\ 3 + m_5 R & \text{if } \gamma = -1. \end{cases}$$

Equating this with (15) a specific form for $m_5 R$ is obtained, which replaced in (20) enables us to obtain a spectrum that can be written as

$$M^2 = 4\omega \left[n + L + \left(\Delta_0 - \frac{5}{2} \right) \right]. \quad (21)$$

Here, just as in the integer spin case and for the same reasons, we have taken $\lambda = 2$. In this way, we have got the same dilaton for all cases considered.

It should be noted that $\gamma = 1$ actually represents two cases. When $2m_5R > 1$ the spectrum is given by (21), which is the result that appears when $\gamma = -1$. On the other hand, the other solution that corresponds to the case $\gamma = 1$ gives an M^2 which is negative.

IV. PHENOMENOLOGICAL IMPLICATIONS.

A. Hadronic spectrum.

In the model that we have presented the general form of the spectrum, for all cases considered, is

$$M^2 = A[n + L + v], \quad (22)$$

where $A = 4\omega$ is the Regge slope, and v is given by

$$v = \begin{cases} \Delta_0 + \frac{\beta}{2} - 1 - S & ; \text{If } S \text{ is integer} \\ \Delta_0 - \frac{5}{2} & ; \text{spin } 1/2. \end{cases}$$

Notice the the model give us the Regge slope in terms of ω , but it does not provide information on how to calculate it, and therefore this constitute a phenomenological input in our model.

(22) can be applied to different kinds of hadrons with an arbitrary number of constituents. Unlike the model presented in [9], where v was a parameter that had to be adjusted for each kind of hadron, and which restricted the predictive power of the model, here we can see that for the integer spin case v depends on Δ_0 and β , where Δ_0 is obtained from the number of quark, antiquarks and gluons in the hadron considered and moreover β depends on the spin, taking a single value for scalars, another value for vectors and so on. After adjusting this parameter using data for a specific hadron, it can be used for other hadrons with the same spin. On the other hand, in the spin 1/2 case v depends only on the number of quarks, antiquarks and gluons in the hadron considered.

Before going into some specific examples, it is relevant to make a brief comment about the Regge slope. The Regge structure for the spectrum is a very good approximation for mesons and light baryonic resonances, and although the adjustment of the slope gives different values for different hadrons, its value changes very little, and therefore with good approximation can be considered universal.

Two adjustments to meson data that produce two mutually consistent slopes give $A = 1.25 \pm 0.15 \text{GeV}^2$ [26] ($\omega \sim 0.313 \text{GeV}^2$) and $A = 1.14 \pm 0.013 \text{GeV}^2$ [27] ($\omega \sim 0.285 \text{GeV}^2$). Adjusting to light baryonic resonances (i.e those formed by quarks u, d and s) gives $A = 1.081 \pm 0.035 \text{GeV}^2$ [28] ($\omega \sim 0.270 \text{GeV}^2$). From this, the value $A \sim 1.1 \text{GeV}^2$ ($\omega \sim 0.275 \text{GeV}^2$) can be considered approximately universal for all trajectories [29].

Note that according the dilaton used ($\Phi(z) = 2\ln(z)$), the dimensionless anomalous dimension is $\delta = \omega e^{\Phi(z)} =$

ωz^2 . With this is clear that ω units must be square of Energy.

1. Scalar hadronic spectrum.

As was mentioned before, we take the value 1.1GeV^2 for the Regge slope ($\omega \sim 0.275 \text{GeV}^2$). We must also fix β , and for this we consider the pion form factor, which as we will see below in section IV.B, is given by (23). This, when $Q = 0$, must be reduced to the normalization condition (19), and then $\beta = -3$, which makes the normalization to be the same as the one that is used in [31].

The spectrum for scalar mesons is shown in Fig 1, while some examples about model prediction for scalar exotic hadrons appear in Table 1. This includes the content of quarks, antiquarks (that contribute with 3/2 to Δ_0) and gluons (that contribute with 2 to Δ_0).

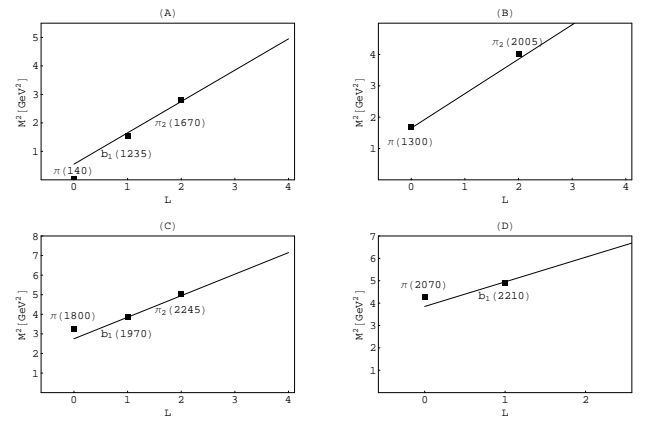


FIG. 1: Spectra of scalar mesons, calculated within the Soft Wall model. The figures correspond to different radial excitations. (A) $n = 0$ (B) $n = 1$ (C) $n = 2$ (D) and $n = 3$.

TABLE I: Scalar exotic hadron masses, with $n = L = 0$. We consider hadrons with n quarks (and / or antiquarks) and m gluons.

Δ_0	(nQ)(mG)	M [GeV]
4	(2G)	1.28
5	(2Q)(1G)	1.66
6	(4Q)	1.96
7	(2Q)(2G)	2.22
8	(4Q)(1G) ; (4G)	2.46
9	(6Q) ; (2Q)(3G)	2.67
10	(4Q)(2G)	2.87

2. Vector hadron spectrum.

In this case we proceed in a similar way as with the scalar case, and we get $\beta = -1$. With this the normalization is the same as the one used in [30], and the Regge slope is the same as the one used above for the scalar case.

The spectrum for scalar mesons is shown in Fig 2, while some examples about model prediction for scalar exotic hadrons appear in Table II.

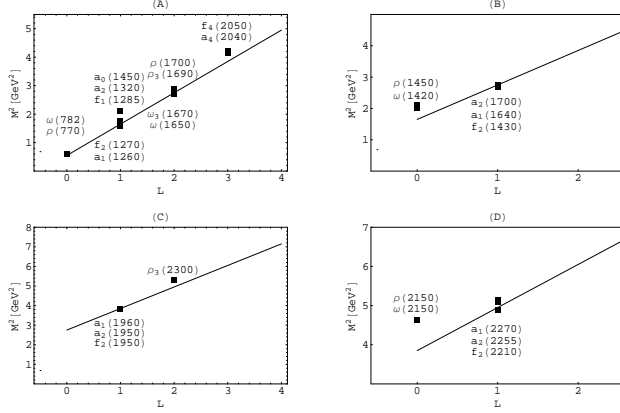


FIG. 2: Spectra of vector mesons, calculated within the Soft Wall model. The figures correspond to different radial excitations. (A) $n = 0$ (B) $n = 1$ (C) $n = 2$ (D) and $n = 3$.

TABLE II: Exotic vector hadron masses, with $n = L = 0$. We consider hadrons with n quarks (and / or antiquarks) and m gluons.

Δ_0	(nQ)(mG)	M [GeV]
5	(2Q)(1G)	1.66
6	(4Q) ; (3G)	1.96
7	(2Q)(2G)	2.22
8	(4Q)(1G)	2.46
9	(6Q) ; (2Q)(3G)	2.67
10	(5G) ; (4Q)(2G)	2.87

3. Spin 1/2 hadron spectrum.

In this case v does not need to be fixed from experimental data. As one can see from Fig 3, using an universal Regge slope gives results somewhat higher than the experiments, but using a value of $0.9 [GeV^2]$ ($\omega \sim 0.225 GeV^2$), adjusted to baryonic data, the results are better.

Both values are used in Table 3, where model predictions for some exotic spin 1/2 hadrons are shown.

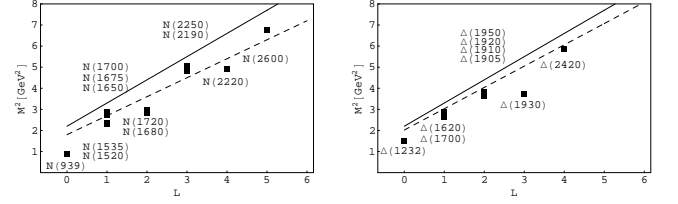


FIG. 3: Nucleons and Δ resonances spectrum. The continuous line is the model prediction using an universal value of $A = 1.1 GeV^2$ ($\omega \sim 0.275 GeV^2$), while the dashed line was obtained using Regge slopes adjusted to each case, with values $A = 0.9 GeV^2$ ($\omega \sim 0.225 GeV^2$) for nucleons and $A = 1.01 GeV^2$ ($\omega \sim 0.253 GeV^2$) for Δ resonances [7].

TABLE III: Spin 1/2 exotic hadron masses with $n = L = 0$. We consider hadrons with n quarks (and / or antiquarks) and m gluons. Column M_U was calculated using $A = 1.1 GeV^2$ ($\omega \sim 0.275 GeV^2$), the universal Regge slope used in this work, while M contains the results obtained using $A = 0.9 GeV^2$ ($\omega \sim 0.225 GeV^2$), a value fixed from nucleon data [7].

Δ_0	(nQ)(mG)	M_U [GeV]	M [GeV]
13/2	(1Q)(3G)	2.10	2.01
15/2	(5Q)	2.35	2.25
17/2	(3Q)(2G)	2.57	2.46
19/2	(5Q)(1G)	2.77	2.66
21/2	(3Q)(3G) ; (7Q)	2.97	2.84
23/2	(5Q)(2G)	3.15	3.01

4. Spin 3/2 hadrons spectrum.

Solutions to Rarita - Schwinger equation in AdS space are more complex to get, but its spectrum is similar to the Dirac case [5, 7]. As is possible to see in Fig 3, again the results are somewhat high, but using $A = 1.01 GeV^2$ ($\omega \sim 0.253 GeV^2$), adjusted to Δ resonances gives better results.

B. Pion Form Factor.

The model described in this work allows to get hadronic spectra and the holographical mode associated to hadrons, with which it is possible calculate form factors in AdS. In this section we are interested in showing that the model, following [31], can be used in aspects of hadronic physics that go beyond the spectrum reproduction. Specifically we consider the pion electromagnetic form factor as an example, calculated in the AdS side.

This application should be considered with some degree of caution, since the pion is not really inside Regge trajectories. Then if one takes the mode with $n = 0$ and $l = 0$ with the same value for ω that was used for the Regge slopes, a good holographical description for the pion is not achieved. For this reason we consider a different value for ω in the pion case.

The form factor in AdS is represented by an overlap integral in the holographical coordinate of the normalizable modes, dual to incoming and outgoing hadrons, φ_p and φ_p , with the non-normalizable mode $J(Q^2, z)$, dual to the electromagnetic source propagating inside to AdS space [23, 31, 32], and which can be written as

$$F(Q^2) = \int_0^\infty \frac{dz}{z^3} e^{-\Phi(z)} J(Q^2, z) |\varphi(z)|^2. \quad (23)$$

Since the non-normalizable mode couples to the dilaton field, $J(Q^2, z)$ is obtained from the solution to (12), with $m_5 = 0$, $P^2 = -Q^2$, $\beta = -1$ and $\lambda = 2$, and then

$$J(Q^2, z) = \frac{1}{2} z^2 Q^2 K_2(Qz), \quad (24)$$

which is equal to 1 when either Q or z go to zero.

For the pion we consider equation (17) with $\Delta_0 = 3$, $n = 0$, $L = 0$ and $S = 0$, and then the mode that describes this hadron is

$$\varphi(z) = C e^{-\frac{1}{2}\omega z^2} z^3, \quad (25)$$

where C is a normalization constant, which is fixed by the normalization (19).

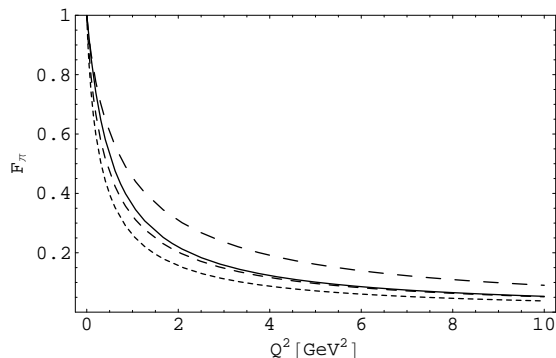


FIG. 4: Pion form factor. The continuous line corresponds to the result obtained in [31], while the dashed lines were obtained using the model proposed here, for different values of ω . The lower dashed line uses $\omega = 0.05 \text{ GeV}^2$, the intermediate dashed line $\omega = 0.07 \text{ GeV}^2$ and the upper dashed line is for $\omega = 0.13 \text{ GeV}^2$.

In Figs. 4 and 5 we show graphs for $F(Q^2)$ and $Q^2 F(Q^2)$, where the continuous line corresponds to the result that appears in [31], while the dashed lines are results obtained with the present model, for different values for ω .

It is important to stress that in this work and in [31], the parameters used for the pion form factor are different from those obtained with Regge trajectories, and this comes from the fact that pions are an exception that does not fall into these trajectories. In fact, in [31] the Regge slope is $4\kappa^2$, and the value of κ used to graph $F_\pi(Q^2)$

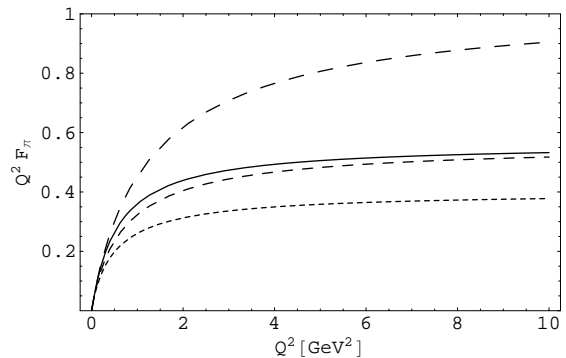


FIG. 5: $Q^2 F_\pi(Q^2)$. The continuous and dashed lines correspond to the same cases considered in the previous graph.

and $Q^2 F_\pi(Q^2)$ is 0.375 GeV . With this value the Regge slope is almost half of the phenomenological value. Pions are therefore an exception, whose parameters have to be fixed in a different way.

Using the obtained pion form factor it is possible to extract the mean square radius for this meson.

$$\langle r_\pi^2 \rangle = -6 \frac{dF_\pi(Q^2)}{dQ^2} \Big|_{Q^2=0} = \frac{3}{2\omega}, \quad (26)$$

This is similar to the expression found in [31]. Considering the values of ω used in Figs 4 and 5 for the results shown in the dashed lines, the values for $\langle r_\pi^2 \rangle$ are $1.17 [fm^2]$, $0.83 [fm^2]$ and $0.45 [fm^2]$. The last value corresponds to the experimental result, here obtained using $\omega = 0.13 \text{ GeV}^2$, which in turn corresponds to the upper dashed line in Figs 4 and 5.

V. CONCLUSIONS.

In the present paper a SW model has been presented, which contains some features that solve difficulties that appear frequently in other models, and that are usually cause for criticism.

First, the model let us obtain hadronic spectrum with Regge behavior, not only for the integer spin case, but also for spin $1/2$ and $3/2$. In order to do this we considered only one metric and one dilaton, unlike what happens in Ref. [7], where a family of metrics was used. Secondly, we considered the anomalous dimension for operators that create hadrons. And thirdly, the dilaton used has a form that was suggested by Einstein's equations, corresponding to the AdS metric that is used [20, 21, 22]. The latter two traits allowed the model to reproduce Regge spectra in all cases considered, and therefore the model can describe baryons in a unified phenomenological model.

In [9] it was shown how to include hadrons with an arbitrary number of constituents, although this was done only for the scalar case. Here this idea has been successfully extended to other hadrons, presenting results for

exotic hadrons with arbitrary integer spin, and for spin 1/2 and 3/2. This was possible due to that unlike in [9], where v in (22) was a parameter that needed to be fixed for each hadron, here we have two situations. In the integer spin case v depends on Δ_0 , and through this it depends on the constituent number (but this is easy to find) and on β , which depends on spin. Then β needs be fixed only one time for scalars, one time for vectors, and so on. On the other hand, for the spin 1/2 and 3/2 cases, v depends only on Δ_0 . For this reason this model is really predictive in the exotic hadronic sector, because the parameters A and v in (22) could be fixed experimentally in some cases and are calculable in others. This did not happen in [9].

An interesting additional fact is the introduction of the anomalous dimension, because this makes m_5 to be z de-

pendent, and this could have an effect on other quantities that depend on scales, like chiral condensates and quarks masses, treated in holographic models [24].

Finally, for the pion form factor it is possible to adjust parameters in a different way, because the pion does not fit into Regge trajectories, and this requires giving it a special treatment at the moment of fixing parameters.

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